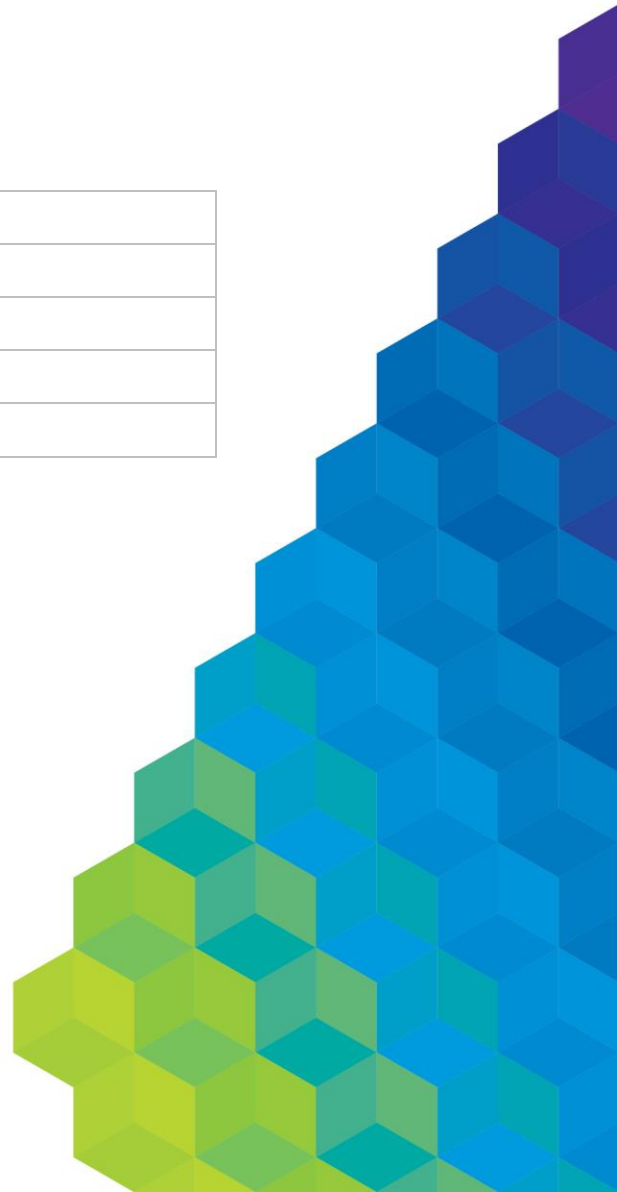

AMS 10-78 Transmission Line Foundations

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Transmission Line Structure Foundations

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Transmission Line Structure Foundations

1 Executive Summary

This document defines the asset management strategies for the Victorian electricity transmission network's population of transmission line structure foundations to maintain the safety, quality and security of supply.

There are approximately 13,000 transmission line structures in service in the transmission network. These structures are supported by six different types of foundations which comprise all components which are located below a point 300mm above the ground line. Different types of structure foundations in service include pier and slab, grillage, pyramid, tripod, bored (augured) and piled.

There have been two structure foundation failures associated with wind events during the early stages of the transmission network, in late 1950s. Investigations attribute the failures to inadequate strength of grillage type foundation designs. Following these incidents, a program of foundation strengthening works targeting structures with grillage foundation designs was undertaken. Since the completion of this strengthening program in 1968 there have been no foundation failures in Victoria.

Transmission line structure foundations are subject to routine condition assessment. Structure footings are generally in very good to good condition. AusNet Services has intrusively inspected and tested footings since 2001. Life extension works (SOXS) such as the application of protective paint and footing reinforcement is performed as part of this process. It is intended to continue these works over the upcoming years as the number of foundations in poor to very poor condition has increased, and functional failures of footings present a high risk.

Some corrosion protection of below ground steel work is achieved by introducing cathodic protection systems. Impressed Current Cathodic Protection (ICCP) has been installed at 24 locations, some at initial construction to protect deep piled foundations from stray DC rail traction currents and some later in life to minimise the negative effects of galvanic (Cu/Zn) currents from terminal station earth grids.

Under line fault conditions electrical fault currents may discharge through tower foundations and create earth potential rise (EPR) at the tower legs and in soil surrounding the structure foundations. AusNet Services has completed an earth resistance testing program aimed at managing risks associated with EPR.

High level strategies to be adopted for prudent and efficient management of the transmission structure fleet are:

1.1 New Assets

- All new structures and foundations are designed and constructed in accordance with current industry guidelines and standards¹.

1.2 Inspection

- Continue to assess the condition of transmission line structure foundations during detail inspections which are conducted at 3, 6 or 9 yearly intervals.
- Continue to monitor the status of tower site and foundation for flooding, vegetation encroachment and erosion to assure the safe performance of all structures.
- Continue the program of inspections for cathodic protection systems, both Impressed Current Cathodic Protection (ICCP) and Cathodic Protection (CP) using sacrificial anodes.
- Continue to test the Earthing Resistance of tower foundations, to mitigate the risks associated with earth potential rise.
- Continue to use Filed Mobile Inspections (FMI) to update the asset information system, SAP during detailed inspection and condition assessment.

1.3 Maintenance

- Continue to perform corrective work on towers which have damaged, missing, corroded members, legs and/or bolts.

¹ AS/NZS 7000:2016 Overhead Line Design – Detailed Procedures.

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- Re-commence the implementation of corrosion mitigation and life-extension work on tower legs in direct contact with the ground, i.e. SOXS program.
- Revisit the tower foundations which have been SOXed starting with the population done in 2001, to confirm the performance of the coating system in preventing further degradation to the steel legs.

1.4 Refurbishment

- Refurbish or upgrade old/malfunctioning corrosion protection systems, i.e. ICCP and SAs which have malfunctioning units and/or exhausted sacrificial anodes.
- Refurbish damaged footings as identified by the regular inspections to assure the safety and performance of the tower.
- Address the issues associated with the 69 tower foundations reported to be in Very Poor condition, C5.

Transmission Line Structure Foundations

2 Introduction

2.1 Purpose

This document defines the asset management strategies for transmission line structure foundations forming part of AusNet Services' regulated Victorian electricity transmission network.

2.2 Scope

This asset management strategy applies to all transmission line structure foundations associated with AusNet Services' regulated electricity transmission network that support circuits operating at voltages of 66kV and above. The strategy applies to foundations of structures situated on lines easements, as well as towers and termination structures also known as rack structures within terminal stations.

This strategy does not include asset management aspects of structure foundations operating on the distribution network, communication towers or masts and structures situated within zone substations.

The strategies in this document are limited to maintaining existing equipment performance. Improvements in quality or capacity of supply are not included in the scope of this document.

2.3 Asset Management Objectives

As stated in [AMS 01-01 Asset Management System Overview](#), the high-level asset management objectives are:

- Maintain network performance at the lowest sustainable cost;
- Meet customer needs now and into the future;
- Be future ready;
- Reduce safety risks; and
- Comply with legal and contractual obligations

As stated in [AMS 10-01 Asset Management Strategy -Transmission Network](#), the electricity transmission network objectives are:

- Maintain top quartile benchmarking;
- Maintain reliability;
- Minimise market impact;
- Maximise network capability;
- Leverage advances in technology and data analytics;
- Minimise explosive failure risk.

Transmission Line Structure Foundations

3 Asset Summary

3.1 Asset Function

Transmission structure foundation include both that part of a structure, called its footing, that support and transmit the gravity and mechanical loads acting on the structure, as well as the soil material upon which the structure is built on.

The foundation supports the structure that allows the transport of power within the network while assuring its reliability and keeping the public and environment safe. This is done by providing a safe platform that allows the structure to support the phase conductors and groundwires at a safe distance from the ground, structures, and vegetation.

Transmission foundations are made from engineered and manufactured components which provide reliability and durability throughout its service life. Most common footings are made from reinforced concrete, or steel lattice members and flat plates.

3.2 Asset Population

There are approximately 13,000 transmission line structures² in service in the transmission network. Transmission line structures support live conductors via strings of line insulators. Different types of structures in service include steel lattice structures, poles, rack structures and ground wire masts.

Structure foundations comprise all components which are located below a point 300mm above the ground line. Different types of structure foundations in service include pier and slab, grillage, pyramid, tripod, bored (augured) and piled. Table 1 provides a brief description of each different structure foundation type.

² AMS 10-77 Transmission Line Structures.

Transmission Line Structure Foundations

Table 1 – Structure foundation types

Foundation	Description
Grillage	Tower leg extends to the foundation base where it connects to a steel grillage.
Pyramid	Four steel members join to the tower leg to form a pyramid shape. This style of foundation may include a grillage or concrete slab at the base.
Tripod	Tower leg extends to the base and two bracing members rise from the base to provide support to the leg. This style of foundation will typically have a concrete slab at the base.
Bored (augured)	A bored foundation is created by drilling a hole in the ground, positioning the tower leg inside a reinforcing cage and backfilling with concrete. The base of the hole may sometimes be under-reamed.
Pier and slab	This foundation type encases the tower leg in reinforced concrete down to a reinforced concrete base.
Piled	Consists of a steel tube driven into the ground and backfilled with concrete, encasing the tower leg. May also use driven solid steel or reinforced concrete piles.
Pole	This refers to pole structure footings directly buried into the ground. These structures have been introduced into the network recently, used primarily if there are constraints in the location such as space, i.e. structure footprint, or community influence, i.e. visually less intrusive.

Bored or augured foundations are the most common types in use on the Victorian network comprising 37% of installations. This type of foundation is the most common due to its relative ease of construction, low cost and high reliability. Grillage, and pier and slab base foundations make up the majority of the remaining foundation type, contributing to 28% and 27% respectively. Figure 1 displays the different types of structure foundations.

Dedicated lattice structures supporting communications equipment

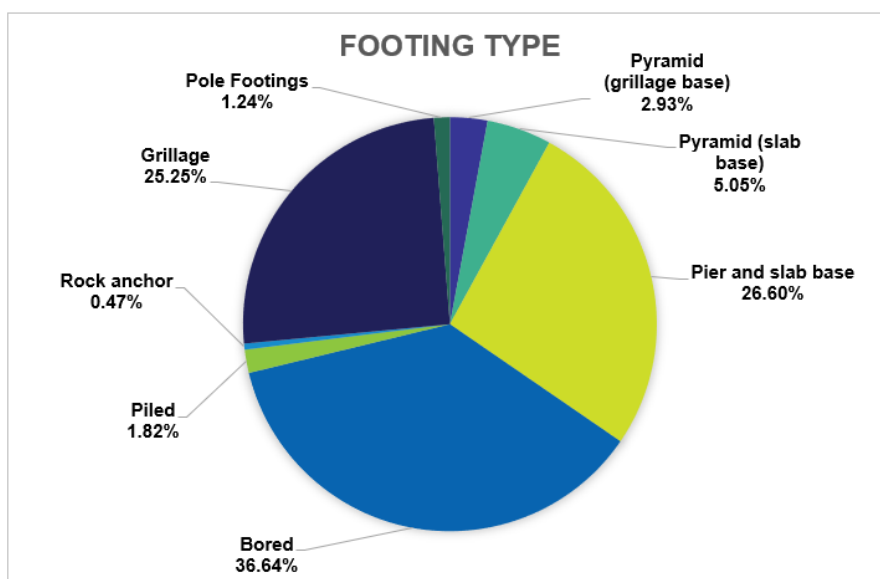


Figure 1 – Structure foundations by type

Transmission Line Structure Foundations

3.3 Age Profile

The Victorian transmission network initially consisted of 220kV lines built to connect Melbourne and large towns, in the North West and North East of the state, to generators in the La Trobe Valley.

Construction of 220kV lines first began in 1950. Connection to the New South Wales network was later achieved via 330kV lines built between the late 1950s and early 1980s. Lines operating at 500kV from the Latrobe Valley to Melbourne were constructed in the 1970s providing further capacity to meet demand growth and to support heavy industry in South West Victoria.

Transmission line structure foundations have the same age profile as their corresponding transmission line structures. The average age³ of the transmission line structure foundation population is about 53 years. Table 2 displays the average age of structure foundations on the Victorian network by operating voltage. Structure foundations on the 220kV network have the highest average age closely followed by the 330kV structures.

Table 2 – Average age of transmission line structure foundations

Voltage Class	Average Age
500kV	41.4
330kV	52.0
275kV	31.0
220kV	53.6
66kV	43.3
Overall Avg.	52.6

Figure 2 displays the age profile of transmission line foundations and their respective structures by voltage class.⁴

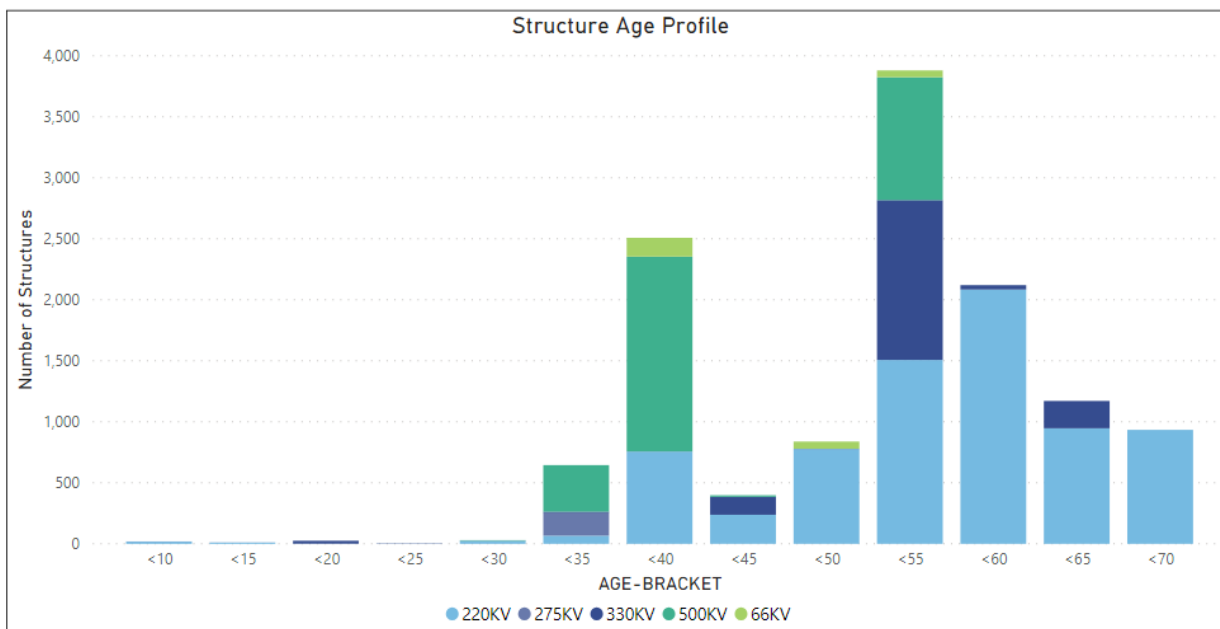


Figure 2 – Structure foundation age profile

³ Service age data for structure foundations is currently based on the construction date.

⁴ AMS 10-77 Transmission Line Structures.

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The structure foundations age profile roughly reflects that of a normal distribution with a mean age of approximately 53 years and a standard deviation of approximately 6 years. This is significant from an asset replacement perspective as subject to different environmental conditions, it is possible that large proportions of the fleet may require replacement within relatively short time frames.

3.4 Asset Condition

3.4.1 Condition Assessment

Condition of transmission line structure foundations is assessed as part of regular detailed inspection of the structure. Inspections are conducted at 3, 6 or 9 yearly intervals, depending on the criticality of the line asset (e.g. structure, insulator, conductor and groundwire) at that specific location.

The condition assessment focuses on the physical condition of the structure footings against corrosion, wear and/or damage due to the environment, ground movement/erosion, and/or imposed by third party activities.

Structure footings are assigned a condition grade from a scale between C1 and C5. Table 3 outlines condition grades for structure members and bolts including a description against each different grading parameter. More detail is described in LPP 09-06: Condition Assessment of Overhead Lines.

Table 3 – Tower foundation condition grades and descriptions

Condition Scoring Methodology				
Condition Score	Condition Description	Tower Leg, steel member or poles	Concrete pedestal (for reinforced concrete)	Remaining Life
C1	Very Good	Good condition, painted	Good condition	95%
C2	Good	First rust spots or minor damage to SOXS coating	Hairline cracks starting	85%
C3	Average	Extensive surface rust	Cracks but no spalling	60%
C4	Poor	Flake rust or SOXS coating cracking	Concrete spalling started	25%
C5	Very Poor	Pitting or SOXS coating peeling/flaking	Concrete spalling which is <10% in cross section	15%

At present, structure foundations are generally in very good to good condition. Approximately 50 percent of structure foundations has no rust or have been painted, and approximately 46 percent is exhibiting first signs of rust. It should be noted that these results reflect conditions at the footings ground line and may not be representative of below ground conditions.

Transmission Line Structure Foundations

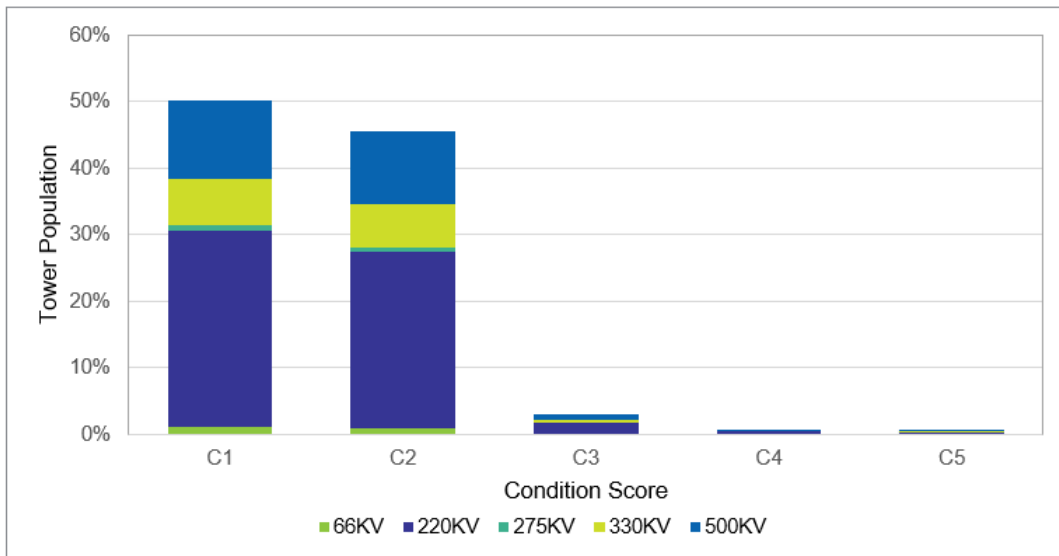


Figure 3 – Structure Foundation Condition

Figure 3 shows that over 96% of the foundations are in a C1 or C2 condition, with 3% in C3 condition, 0.7% in C4 and 0.3% C5 condition.

3.4.2 Structure Foundation Condition vs Corrosivity Zone

The assessment of the condition of transmission line structure foundations is done during tower inspections. To identify ground-level corrosion of direct buried tower leg steelwork, it is necessary to perform shallow excavations at the tower legs and inspect the exposed steelwork. The most common and visible form of corrosion is at ground level where oxygen is abundant, and members are subject to constant wetting and drying, solar radiation and greater thermal cycling. Tower leg members and braces can also be damaged following impact from vehicles or farming machinery. Above-ground steel leg-to-concrete interfaces may be assessed by visual inspection and do not require excavation.

Footings are assigned a condition grade from a scale between C1 and C5 against two grading parameters: leg and bracing members, and if the tower is on concrete foundations, the concrete pedestal. The towers located in Corrosivity Level 3 have foundations in Very Good to Average condition (C1 to C3) because these have been painted together with the tower structure in 2002. Refer Figure 5 for condition profile against the tower population.

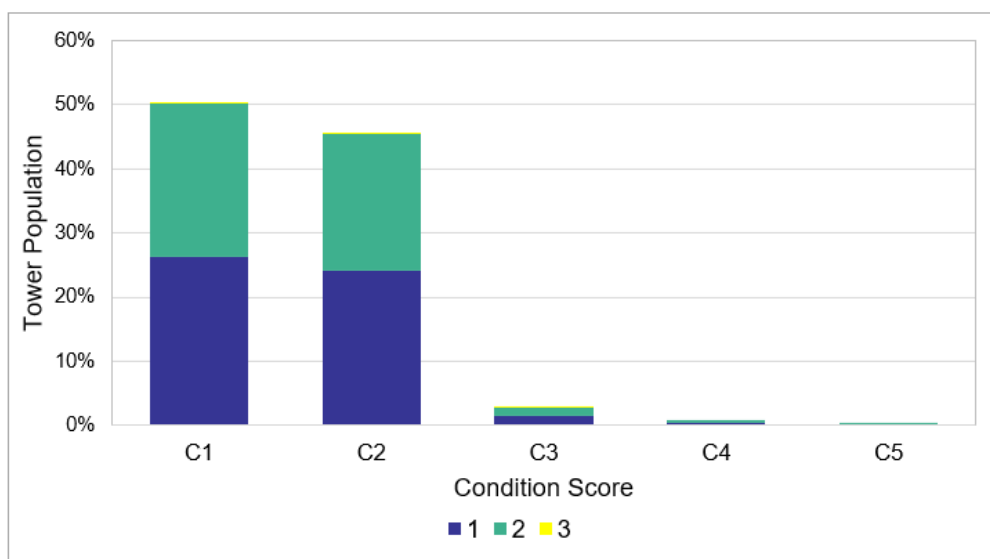


Figure 4: Structure Footing Condition vs Corrosivity Zone

Transmission Line Structure Foundations

3.4.3 Structure Foundation Condition vs Age

Figure 5 shows that the transmission line structure footings reflects that of a normal distribution with a mean age of approximately 53 years and a standard deviation of approximately 6 years. The figure shows that even in the advanced age of foundations, most of these are still in very good to good condition (C1 to C2).

This would be attributed to the SOXS program which addressed the issue of degradation due to corrosion, thereby assuring the integrity of the transmission network and therefore, its safety.

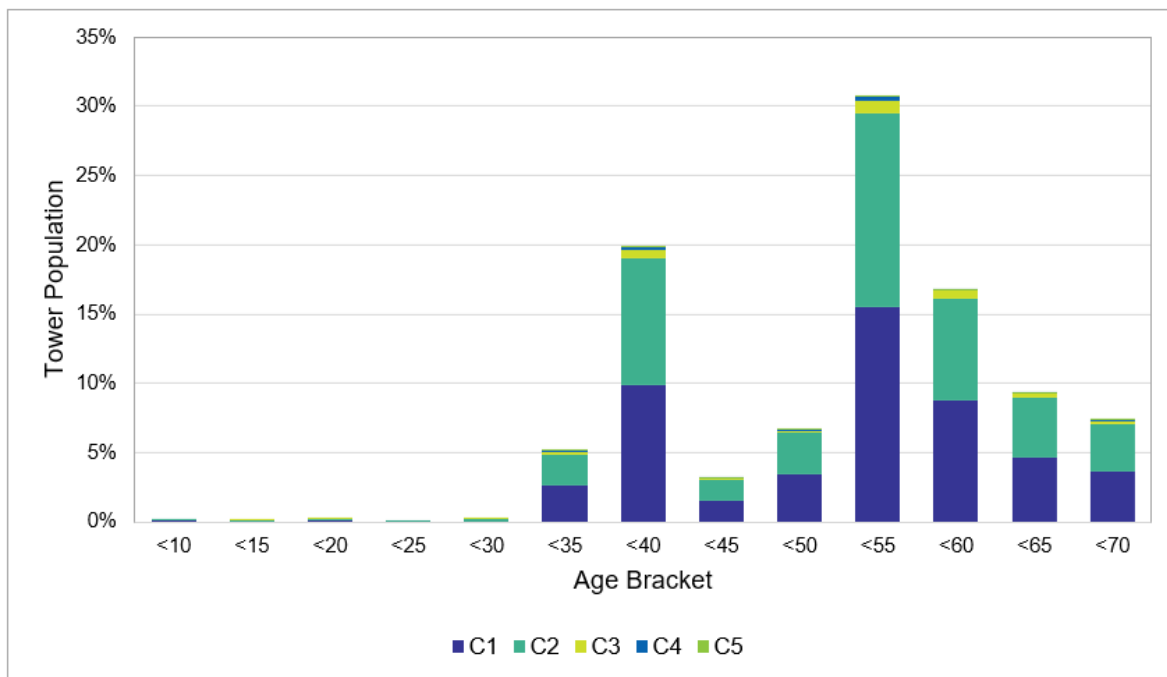


Figure 5 – Structure Condition Footing across Service Life

3.5 Asset Criticality

The consequence of failure of a transmission line structure foundation can result in the structure and live conductors falling to the ground with significant effects or consequences. The consequence can be categorised into five bands based on its economic impact. These discrete groups called Criticality Bands are independent of the structure's likelihood of failure.

The economic impact is calculated by adding these components:

- Bushfire ignition
- Health and safety
- Value of unserved energy/ Market impact
- Collateral damage to adjacent AusNet Services property
- Third party property damage

3.5.1 Bushfire ignition

Failure of structure foundations resulting to transmission line assets falling to the ground can result in discharges of energy which are capable of igniting ground fires. Some transmission lines are situated in easement through high density fuel loads in grasslands and forests. In extreme weather conditions ground fires started close to such fuel loads can quickly develop into widespread bushfires.

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Bushfire loss consequence modelling performed by Dr. Kevin Tolhurst⁵ of Melbourne University has enabled the establishment of quantitative bushfire consequence values for transmission line assets. The bushfire loss consequence model demonstrates that functional failure of a transmission line structure could trigger a bushfire incident with a risk ranking score of II as per the AusNet Services risk matrix. A map displaying the bushfire consequences associated with transmission line assets is shown in the appendix of the Asset Management Strategy for Transmission Line Structures⁶.

Although historically there have been no instances of fire ignition following a functional failure of a structure foundation, there has been one incident where a structure failure triggered a small ground fire. In 1981, a ground fire ignited following a structure collapse on the Murray switching station to Dederang 330 kV No.2 line caused by extreme winds during a storm event. The fire was relatively small and was extinguished by rainfall during the storm event.

Even though this event was the result of a structural failure, the outcome would probably have been the same if the structure collapsed due to a foundation failure.

3.5.2 Health and Safety Impact

Transmission line easements traverse both public and private land and in many instances, these are shared or located next to other infrastructure such as roads, railway lines, pipes and fences. Structural foundation failures present risks to members of the public, particularly with structures adjacent to roadways, railway lines and public areas such as car parks, parks and gardens.

Using the results of a study performed by Vic Roads⁷ in 1994, a quantitative consequence assessment of transmission line spans which crosses roads and railways has been completed. The assessment has revealed that a major foundation failure leading to a tower collapse event could cause a health and safety incident with a maximum risk rating score of II as per the AusNet Services risk matrix.

Easement use types are categorised as urban, rural developed and rural undeveloped. Urban easement segments traverse over built-up private properties and on the other end of the spectrum, rural undeveloped easements are bare country properties. The health and safety consequence of a foundation failure resulting to a structure collapse event has been calculated for each easement type.

3.5.3 Unserved Energy / Market Impact

The electricity transmission lines forming the National Electricity Market have high levels of redundancy under average loading conditions. However, at peak loading periods, transmission line failures can constrain generator connections causing a re-scheduling of generators in other states, and/or load shedding may be required to provide network security for a subsequent un-related failure.

The Australian Energy Market Operator (AEMO) conducts a study which identifies the amount customers are willing to pay to assure the reliability of their supply. This amount, called the Value of Customer Reliability (VCR), is used to monetise the consequence of the terminal station not being able to provide the load demand by the market, called the Value of Unserved Energy (VUE).

Another impact of lines becoming out of service is the need for AEMO to re-dispatch energy from a different generator (usually a gas generator) due to a line fault that either impacts the line directly, i.e. line is out of service so connected generator can't export energy to the market, or indirectly, i.e. the line outage constrains a certain part of the network so AEMO has to source power somewhere else to meet the load demand.

Foundation functional failures will result to transmission line structure failures and circuit outages which negatively impact on performance levels within the incentive schemes. Impacts on the schemes are compounded when major failures take place on radial lines or cause constraints on electricity generation. Financial penalties likely to be imposed can be calculated using guidelines set out by the Australian Energy Regulator (AER).

3.5.4 Collateral damage to adjacent AusNet Services towers/assets

The electricity transmission network was built in stages, using technical standards and foundation designs that were current on that period.

⁵ A Bushfire Risk Assessment for the SP-AusNet HV Network in Victoria 2011.

⁶ AMS 10-77 Transmission Line Structures

⁷ Bureau of Transport and Communications Economics (1994) The Costs of Road Accidents in Victoria – 1988.

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Over time, built on improved knowledge and industry practice, technical standards and footing designs were updated to become more appropriate to the weather events, e.g. wind and snow loads, as well as construction and maintenance loads structures and its components will support, e.g. out-of-balance loads, broken conductor loads, etc.

This situation means that assets built using older standards and footing designs are more susceptible to fail in multiples, especially if these are connected in series, e.g. when a high wind event results to multiple collapsed towers.

The consequence of this event has been monetised by considering the design standards at the time of an asset's construction, and the potential damage inflicted on adjacent AusNet Services assets if it fails, i.e. cascade failure of towers.

3.5.5 Damage to third party property

Damage caused to third party property considers the consequence of a foundation failure resulting to a tower, conductor and groundwire on the ground. The consequence depends on the easement use which are categorised as urban, rural developed and rural undeveloped.

Urban easement segments traverse over built-up private properties and/or councils while on the other end of the spectrum, rural undeveloped easements are bare country properties. The damage to properties, e.g. fence, roof, shed, swimming pool, tennis courts, etc. owned by third parties have been calculated for individual spans and used in the analysis.

3.5.6 Overall Criticality

The consequences of a foundation failure can be allocated into five criticality bands. This is based on their economic impact cost, as the result of the failure relative to the cost of replacement of the asset. These asset criticality or consequence impacts are irrespective of the likelihood of the actual failure.

The five criticality bands are tabulated given in the Table 4 below:

Table 4 – Criticality Band

Criticality Band	Economic Impact due to a failure
1	<= 1 x replacement cost
2	1 to3 x replacement cost
3	3 to 10 x replacement cost
4	10 to30 x replacement cost
5	>30x replacement cost

The criticality assessment compares calculated consequence cost with replacement cost. Refer Table 7 Section 5.2 for the criticality-condition risk matrix for the structure foundation fleet. The numbers indicate the quantity of structures which are under a specific condition score and have a consequence of failure.

3.6 Performance

3.6.1 Suspended failures

AusNet Services has implemented line inspection and condition assessment practices which provide information for objectively estimating the Remaining Service Potential (RSP) of transmission line components or assets and where necessary, undertake timely remedial action. Transmission line structure foundations which require remedial works are identified by raising condition-based notifications (ZA Notifications). Structure foundations actioned via work orders do not cause transmission line functional failures and so are classified as suspended failures for Reliability Centred Maintenance asset management purposes.

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Over the last five years there have been a total of 339 suspended foundation failures. The majority of the suspended failures were caused by deterioration of legs, k-brace and pedestals. These represent 50% of the total suspended failures while corrosion of members and legs comprise 20%. In most cases rust was found on the tower legs at the ground line where the mix of air and moisture most promotes corrosion. Corrective actions taken to address corroded tower legs involves member strengthening if section loss is identified, cleaning of rusted members and the application of protective paint.

Figure 6 displays suspended failures by cause over the last five years. Peaks in volumes of ZA notifications reflect corrosion and wear-based issues. Failure rates for corroded tower legs and braces have reduced considerably over the last four years.

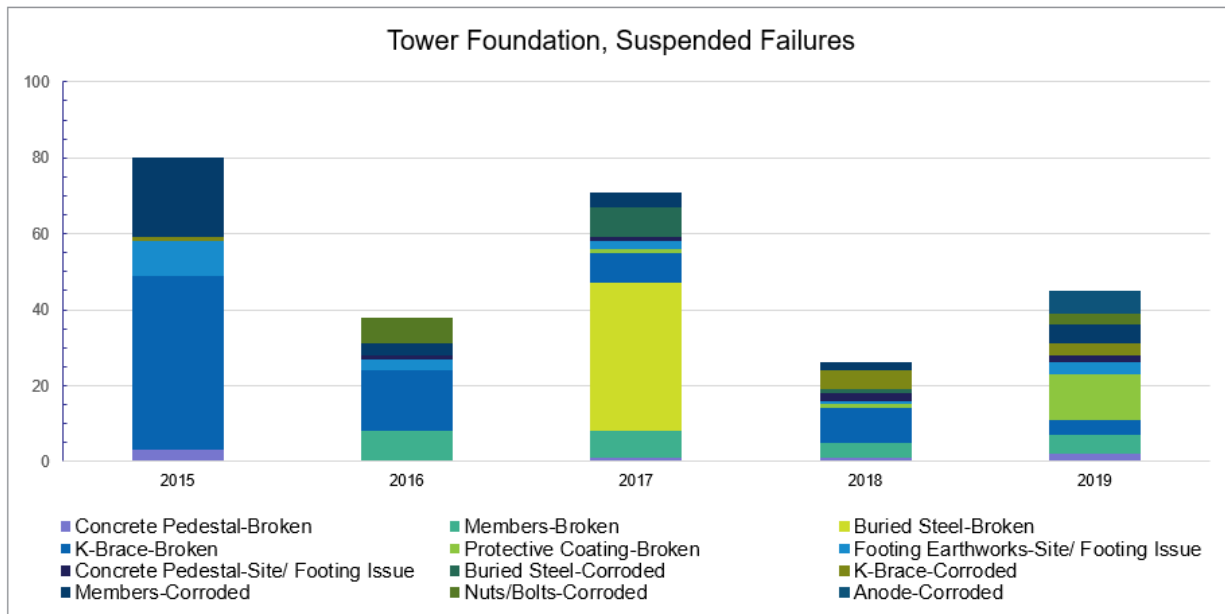


Figure 6 – History of suspended foundation failures

3.6.2 Functional failures

Since 1958 there have been two incidents of structure foundation functional failures resulting to 8-tower collapses as indicated in Figure 7. In this context a functional failure of the structure’s foundation results in a functional failure of the transmission line. Such a failure prevents the safe flow of electricity from one terminal station to another which has marginal market costs and unserved energy costs to the community. Other risk costs arising from a functional failure of a structure’s foundation include unplanned structure replacement, and potential public safety risks associated with failures near roads, railway lines or in areas defined as a high bush fire risk.

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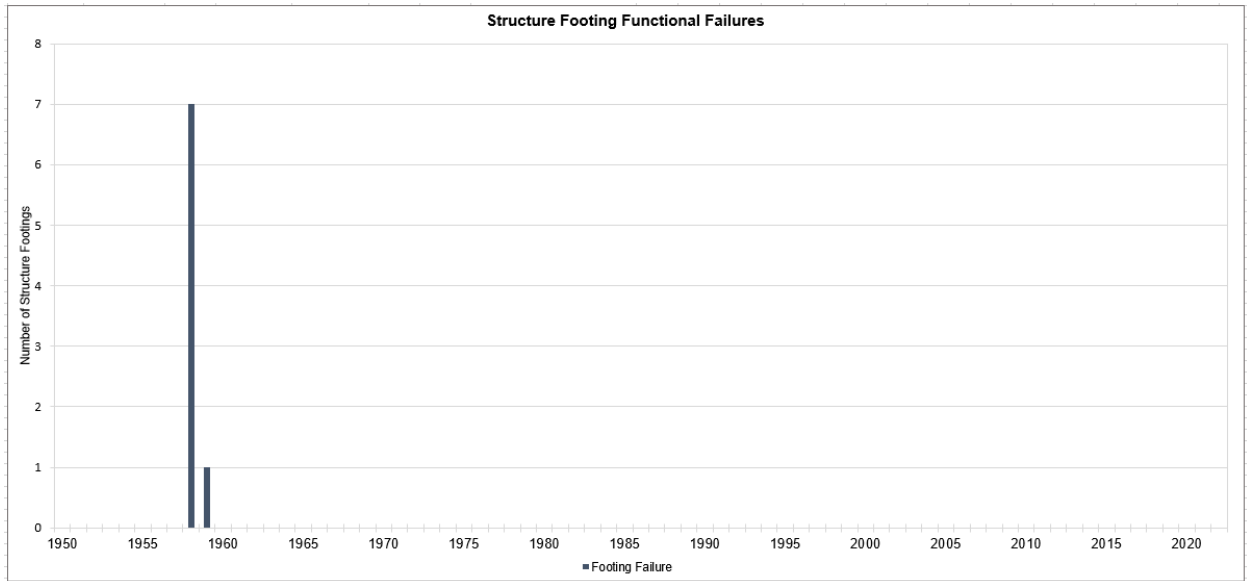


Figure 7: Foundation functional failure history

Although unrelated, the two incidents took place within a period of two years in the late 1950's when the transmission network was still under construction. These failures were caused by inadequate strength of grillage type foundation designs. Following these incidents, a program of foundation strengthening works targeting structures with grillage foundation designs was undertaken.

Line Name	Voltage	No. of Circuits Affected	Year Constructed	Failure Date	Location	Tower Type	Tower Numbers	Failure Mechanism	Storm Type
MLTS-TGTS (Geelong-Colac)	220	1	1957	1/05/1958	approx 30km from Point Henry	Suspension	(7) Nos. 82-88	grillage foundation failure in tower No.88	no abnormally high winds
MBTS-EPS (Kiewa-Melbourne)	220	2	1955	1/02/1959		Suspension	(1) No. 190	grillage foundation failure	severe wind storm

5 summarises the history of foundation functional failures.

Table 5 – Summary of foundation functional failures

Line Name	Voltage	No. of Circuits Affected	Year Constructed	Failure Date	Location	Tower Type	Tower Numbers	Failure Mechanism	Storm Type
MLTS-TGTS (Geelong-Colac)	220	1	1957	1/05/1958	approx 30km from Point Henry	Suspension	(7) Nos. 82-88	grillage foundation failure in tower No.88	no abnormally high winds
MBTS-EPS (Kiewa-Melbourne)	220	2	1955	1/02/1959		Suspension	(1) No. 190	grillage foundation failure	severe wind storm

The mean time between failures of transmission structure foundations has remained very high at 35 years since no foundation has failed since the tower foundation strengthening works were completed by the State Electricity Commission of Victoria (SECV) in 1968. Figure 8 provides the graph showing MTBF of structure foundations.

Transmission Line Structure Foundations

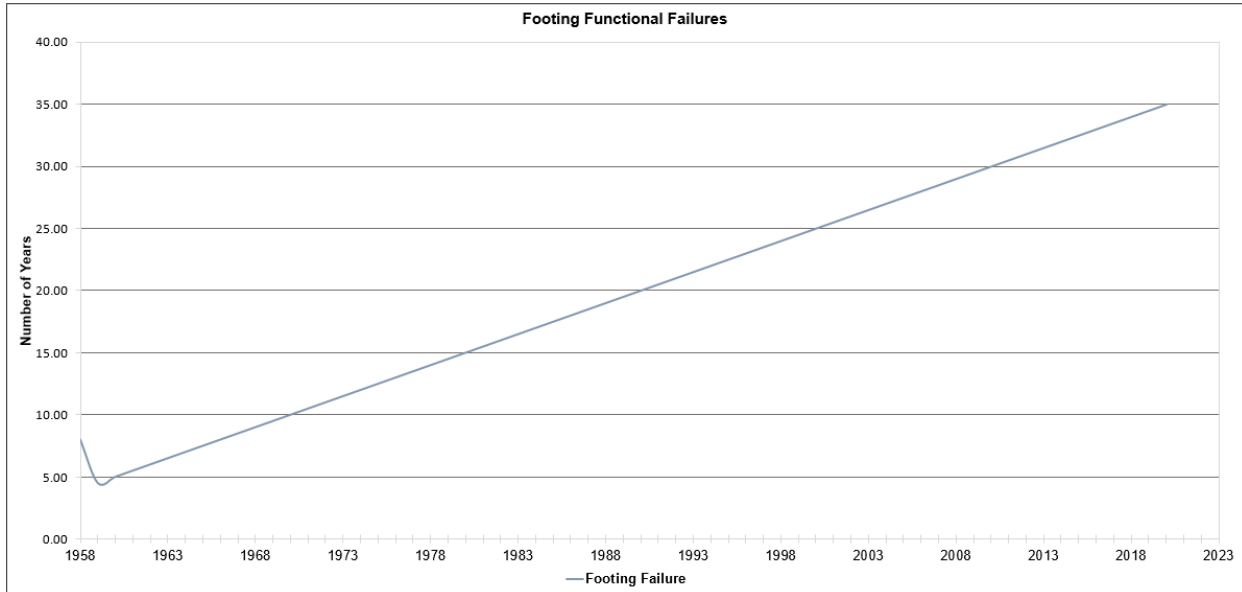


Figure 8: Transmission Structure Foundation MTBF

3.6.3 Tower foundation upgrade works

Inadequate design was found to be responsible for the foundation failures in the tower fleet and remedial construction works were undertaken to strengthen the foundations listed in Table 6.

Table 6 – Summary of foundation functional failures

Circuit Name and number	Year constructed	Date strengthened	Type of strengthening	Number of structures strengthened
YPS-ROTS 5&6	1953	1965	Added concrete pedestal to footing	284
RWTS-TSTS	1956	1960	Installed concrete muffs at ground level to transfer shear force to ground	36
ROTS-MTS	1965	1968	Added concrete pedestal to footing	22
MBTS-EPS	1955	1965	Installed concrete muffs at ground level to transfer shear force to ground	121
EPS-SMTS	1950	1965	Added concrete pedestal to footing	184
SMTS-TTS	1950	1960	Added concrete pedestal to footing	8
EPS-TTS	1950	1965	Added concrete pedestal to footing	184
MLTS-TGTS	1962	1965	Added concrete pedestal to footing	184

The absence of foundation failures after installation of strengthening infers that the strengthening successfully addressed the weaknesses in the original foundations.

3.6.4 Corrosion Mitigation Program, SOXS Works

In 2001 AusNet Services began intrusive inspections targeting direct buried steel legs; this program is known as the SOXS program. This process involves the excavation of the top end of footings (400mm to 500mm below

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ground) which enables a visual inspection of otherwise buried footing legs. Most of the footing legs inspected will have minimal zinc loss which will be coated with a tough protective paint coating, footings are then back filled.

If significant rust or metal loss is discovered, the excavation is continued down the leg to ensure that compromised members do not remain undiscovered. With appropriate precautions such as tower guying, the entire footing may be excavated for detailed inspection. Once excavated the footing members are sandblasted until clean, steel loss is then measured using callipers and recorded on an inspection sheet. Remedial actions are implemented depending on the amount of section loss identified.

If less than 10% section loss is detected the footing steelwork is painted with Ultra High Build (UHB) epoxy paint or Glass flake vinyl ester paint systems to protect exposed steelwork. If more than 10% section loss is identified, engineering assessments are performed to determine what remedial actions are required. Typical actions include the replacement or reinforcement of badly corroded or damaged members.

Light strain or suspension towers are usually reinforced using steel angle splices which are bolted across the deteriorated section of the member(s)⁸. Degraded footings of heavy strain towers situated next to stations racks cannot be economically or safely repaired due to high unbalanced conductor loading so full rating and longevity is restored using concrete piles driven on either side of the existing footing with a tie-beam connecting the piles with the tower leg at a ground level plinth.

The SOXS program targets direct buried steel footings as a priority as these are amongst the earliest built lines and primarily targets direct buried steel footings which were situated close to terminal stations. Direct buried steel footings are prioritised based on the criticality of the line. Structures supported by other footing types are inspected visually during annual tower line inspections and regular condition assessment inspections.

Figure 9 illustrates the percentage of footings completed each year, as an accumulated fleet total and the future forecasts of the SOXS program. Approximately 50% of footings were completed by the end of the 2011/12 financial year.

Since 2015, no tower foundation has been subjected to the SOXS program as it was observed that more than 90% of the towers that were inspected intrusively did not have any corrosion issues. AusNet Services intends to re-commence with the SOXS program over the coming years as indicated by the condition of 160 tower foundations (1.2% of tower fleet) that have deteriorated to C4 and C5 condition.

⁸ AMS 10—77 Transmission Line Structures.

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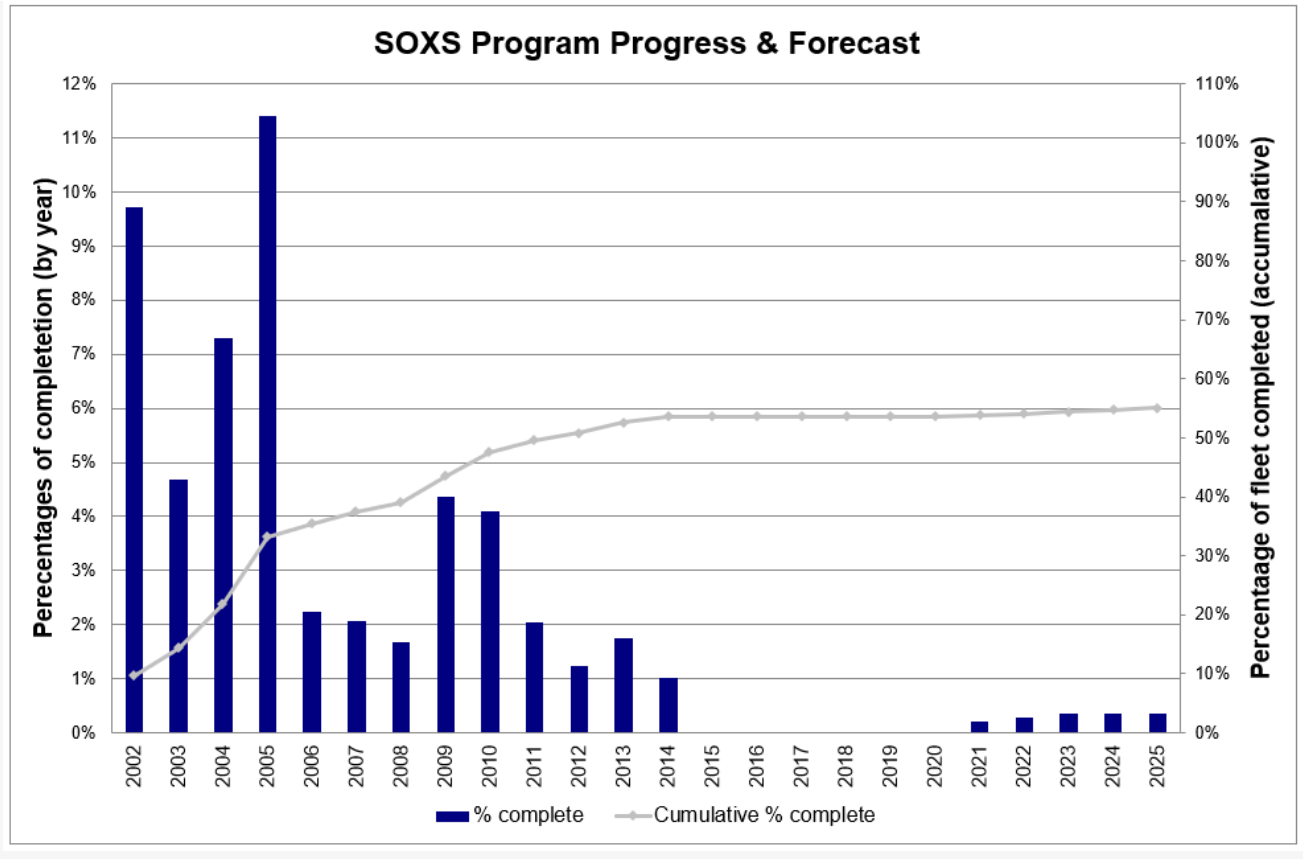


Figure 9: SOXS program progress and forecast

A risk-based decision making process map is used as part of the intrusive and testing process is shown in Figure 10.

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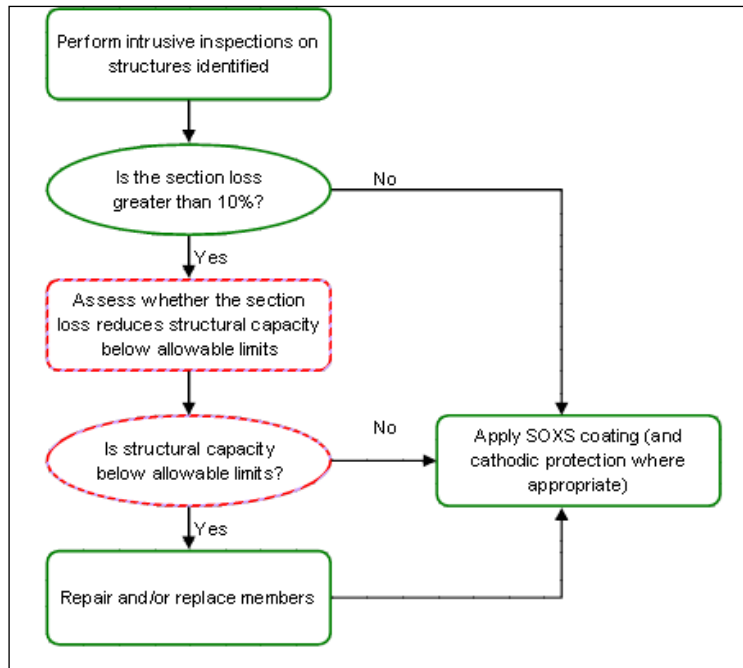


Figure 10: Intrusive inspection of structure foundations decision-making process

The first key decision in the process relates to the need to perform a structural capacity assessment, this decision is made based on the amount of metal section loss measured on the structure foundation members.

Risk assessments performed with close consideration of existing design standards⁹, and design standards used in the construction of existing structures, highlight that section losses above ten per cent present unacceptable risks due to reduction of steels inherent material strength over time. Structures with more than ten per cent section loss may or may not be suitable for the application of protective painting to strengthen the structure.

Reductions of inherent material strength coupled with section losses greater than ten per cent reduce the structural capacity of the foundation to levels close to the structural load. When the structural load exceeds the structural capacity, the structure will fail. Risk assessment outcomes therefore indicate that foundations with section loss greater than ten per cent may not be suitable for cleaning and painting (SOXS) alone and firstly require a structural capacity investigation.

The second risk assessment is performed as part of the structural capacity investigation. The objective of this risk assessment is to quantify the level of risk and determine the optimum corrective action required. This secondary risk assessment is more detailed than the first and is performed as part of technical engineering assessment. Consideration is given to key factors such as soil types, soil corrosivity, rates of metal corrosion, typical wind loads, local topology, structure orientation, structure and foundation design, proximity of structure to roads/railways and criticality of transmission line in terms of financial incentive scheme performance. The outcome of this risk assessment informs asset managers on the extent of remedial actions which include whether to clean and paint (SOXS), repair or replace members, reinforce or replace foundations.

⁹ AS/NZS 7000:2010 Overhead Line Design – Detailed Procedures.

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4 Other issues

The key issues associated with the transmission line structure foundations are as follows:

- Concrete pedestals have been identified as damaged during line patrols. If remedial action is not taken, moisture can enter the structural element which will cause the steel reinforcing bars and legs to develop further corrosion, which in turn decreases the strength of the foundation. The deterioration will eventually require extensive repairs or foundation replacement.
- Soil erosion can occur on tower sites due to environmental factors such as wind, removal of vegetation or changes in water levels, as demonstrated by three 220 kV tower foundations located outside Hazelwood Power Station. These have had gabions installed on the banks to prevent further erosion.
- Corrosion of transmission line footings is accelerated in some areas due to exposure to harsh environmental conditions especially in coastal regions or areas of industrial pollution.
- Structures near electrified infrastructure such as train lines, tram lines, gas pipelines and electrified stations are subject to circulating currents which can cause the electrons of steel to migrate leading to corrosion. These footings need to be protected by installing cathodic protection, as what was done recently to two towers at Ringwood which are located near an electrified train line.
- Structure foundations, specifically the legs can be damaged following impact from vehicles and farming machinery or can be removed by unauthorised third parties.

4.1 Cathodic Protection System

Sacrificial anode Cathodic Protection (CP) and Impressed Current Cathodic Protection (ICCP) systems inhibit metal loss by changing the DC voltage relationship between the structure and surrounding soil. CP does this by promoting corrosion of a sacrificial anode. It is far more cost effective than attempting to protect deep exposed steel with SOXS type coatings. ICCP units are installed where towers are bonded to substation earth grids and the current required to prevent corrosion of the galvanized steel is outside the voltage and current range that can be delivered by sacrificial anodes.

There are currently 15 CP sites and 24 ICCP sites in service, the majority of which are connected to structure foundations next to terminal stations. Cathodic protection was first used on the transmission network in 1970 to protect structure foundations close to West Melbourne Terminal Station (WMTS). These units were required to mitigate the adverse effects of stray current on the structure foundation steel work. CP and ICCP units have been installed progressively between 1970 and 2005.

Regular inspections of these installations include bimonthly current readings for ICCP units, and surveys of anodes on CP and ICCP units every 2 years. These inspections have identified that on some installations the sacrificial anodes will have to be replenished as well as the replacement of the transformer rectifier units on some ICCP installations.

In the last three years, 2-tower foundations had cathodic protection (CP) installed due to their proximity to the electrified train system, while one tower had CP installed on its sheet pile to prevent it from corroding due to its exposure to the Yarra River.

4.2 Structure Electrical Earth Testing

Overhead transmission lines can be struck by lightning during storms triggering line fault events. Under fault conditions fault currents may discharge through the tower foundation and create Earth Potential Rise (EPR) at the tower legs and in soil surrounding the structure foundations. EPR can cause property damage and presents health and safety risks. Poor earthing of structures can lead to line outages following lightning strikes as high resistance drives up structure voltage rise to cause insulator flashover. The subsequent circuit power arc discharge is identified by the electrical protection systems which de-energises the phase conductors.

The electrical resistance of the tower foundations to the general mass of earth are measured during tower construction to verify that the foundation resistances are within accepted limits leading to reliable protection operations and ensuring EPR is within safe limits. The performance requirements of the earthing system may need to change over time for the following reasons:

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- changes in ground conditions
- damage to the earthing system
- A lower earth resistance may be required due to increased line fault current
- A lower earth resistance may be required due to changes in the environment surrounding the structures location (e.g. land usage, public access frequency and bushfire risk).

Analysis of line outage data assists in identifying transmission lines with possible earthing issues. Lines with high outage frequency due to lightning are targeted for structure earth testing. Findings from the resistance tests inform risk assessments and determine the priority and scope of rectifications works.

The earth resistance of the foundations along the HWPS-ROTS 220kV Nos. 1 and 2 lines, which suffered a double outage in February 2010, have been tested and specific towers have been identified for earthing improvement – to be undertaken as a project. The MBTS-DDTS 220kV Nos. 1 and 2 lines will likewise be tested so the line's foundation resistance can be determined and, if necessary, improved.

It is likely that other lines will have to be included in the future test program as the earthing resistance worsens (i.e. becomes higher) as the soil properties change and the foundations deteriorate due to corrosion or natural degradation.

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5 Risk Assessment

To manage transmission line structure foundations in a prudent and economic way, AusNet Services has undertaken fleet wide risk assessments using semi-quantitative analysis. Structure foundation failure risk assessments support asset management planning and ensure that risks associated with structure foundations are managed appropriately.

5.1 Overview

The Risk Matrix or Consequence/ Likelihood methodology is a semi-quantitative analysis using numerical, ordinal or interval scales to rate the consequence and/or likelihood of an event occurring. This type of risk analysis is used to assess overall network risks and specific high-level risks, such as bushfire ignition, health and safety, market impact/value of unserved energy, and collateral damage.

This process brings together asset condition data, asset failure rates, the design standard used for the structure, and the cost impact of asset failure to determine an economically justifiable level of replacement. This section summarises the reliability modelling of structure fleet's foundation.

Key inputs to this process are as follows:

- asset condition of the tower leg and if it exists, the concrete pedestal
- remaining service potential (RSP %)
- failure rate and
- the failure effects¹⁰.

Structures situated in the "severe" corrosivity zones have considerably shorter lifecycles when compared to assets in the "moderate" and "low" corrosivity zones.

AMS 01-09 *Asset Risk Assessment Overview* provides more detail in the Consequence/Likelihood Matrix.

5.2 Risk Assessment Methodology

The risk matrix methodology is a semi-quantitative process wherein the structure fleet's foundations is presented in a 5 x 5 matrix using condition and criticality as its axes.

The methodology is used to identify the population of structure foundations which is economic to refurbish during next regulatory period. The volume only includes assets which are owned by the Regulated Business, as discussed in section 2.2.

- Life Expectancy is based on actual and suspended failures, as well as calculating a structure leg's service life based from corrosion rates¹¹.
- Characteristic age, Eta (η) and Failure Shape Factor, Beta (β) were derived using the Weibull module of the software program, Availability Workbench
 - Structure foundations that have failed (pull-out) are attributed to high intensity wind events which are random in nature.
 - Steel members that were replaced are represented in the analysis by entering its age (in hours) during the time of replacement. These assets are identified as being "suspended failures"
 - The program is made to execute its analysis and the Beta and Eta values are provided
- Weibull parameter calibration is achieved by:
 - Calibrate Eta and Beta to arrive at similar number of failures¹² as experienced in practice.

¹⁰ Effect costs were calculated against each of the possible failure effects discussed in section 3.5 including bushfire ignition, health and safety, value of unserved energy and collateral damage. The total failure effect cost for each asset was taken as the sum of all failure effects

¹¹ A project was undertaken in 2015 which span for 3 years wherein steel coupons were installed on towers at various areas in the transmission network and exposed to the environment. Every year coupons were collected and weighed to determine the rate of section loss due to corrosion. At the end of the project, the annual corrosion rate was calculated, and three Corrosivity Zones were established.

¹² Failures represent actual and suspended failures.

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- All calculations were made using the actual structure population for each condition score bracket and separately for each corrosivity area.
- The Criticality Score is assigned to each structure footing by adding all the consequences of a structural failure, dividing the value by the replacement cost of the structure, and then grouping this into criticality bands as per Table 4 in Section 3.5.

5.2.1 Structure Footing Risk Matrix

The Risk Matrix methodology for the entire foundation fleet indicates that there are 69 transmission structure foundations (0.50% of the foundation population) that need to be refurbished for the period FY2022/23 to FY2027/28. These foundations belong to Risk Category A while the others are in Very Poor, C5 condition.

The risk matrix showing the quantity of structures in Risk Category A is shown in Table 7.

Table 7 – Structure Foundation Risk Matrix

Criticality	CONDITION					Grand Total
	C1	C2	C3	C4	C5	
5	256	239	13	0	1	509
4	635	609	28	4	3	1279
3	1674	1484	104	21	14	3297
2	2230	1973	140	39	23	4405
1	1441	1344	80	32	20	2917
Grand Total	6236	5649	365	96	61	12407

The appropriate action for these foundations varies from cleaning the footing of surface corrosion and application of a coating system (i.e. SOXS works), adding new members to strengthen the leg and then application of a coating system for corrosion protection, or having to modify the foundation to assure the safety and reliable performance of the tower structure.

5.3 Proposed Program of Works

The proposed program of works recommends the selective refurbishment of 65-tower structure footings which are in Poor and Very Poor condition. Table 8 identifies the top ten circuits containing 52% of the structure footings in the program, with the complete list found in Appendix A.

Table 8 – Structure Foundation Risk Matrix

Circuit Name	220KV	275KV	330KV	500KV	66KV	Grand Total
DDTS-SMTS 2			6			6
YPS -ROTS 8	5					5
HOTS-RCTS	4					4
HWPS-ROTS 2	4					4
BETS-KGTS	3					3
DDTS-SHTS	3					3
HWTS-ROTS 3				3		3
SHTS-BETS	3					3
BATS-TGTS	2					2
DPS -MBTS	2					2

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6 Strategies

Implementation of the following strategies is required for prudent and efficient management of transmission line structure foundations:

6.1 New Assets

- All new structures and foundations are designed and constructed in accordance with current industry guidelines and standards¹³.

6.2 Inspection

- Continue to assess the condition of transmission line structure foundations during detail inspections which are conducted at 3-, 6- or 9-yearly intervals.
- Continue to monitor the status of tower site and foundation for flooding, vegetation encroachment and erosion to assure the safe performance of all structures during annual line and easement patrol
- Continue the program of inspections for cathodic protection systems, both Impressed Current Cathodic Protection (ICCP) and Cathodic Protection (CP) using sacrificial anodes.
- Continue to test the Earthing Resistance of tower foundations, to mitigate the risks associated with earth potential rise.
- Continue to use Filed Mobile Inspections (FMI) to update the asset information system, SAP during detailed inspection and condition assessment.

6.3 Maintenance

- Continue to perform corrective work on towers which have damaged, missing, corroded members, legs and/or bolts.
- Re-commence the implementation of corrosion mitigation and life-extension work on tower legs in direct contact with the ground, i.e. SOXS program.
- Revisit the tower foundations which have been SOXed, starting with the population done in 2001, to confirm the performance of the coating system in preventing further degradation to the steel legs.

6.4 Refurbishment

- Refurbish or upgrade old corrosion protection systems, i.e. ICCP and CPs which have malfunctioning units and/or exhausted sacrificial anodes.
- Refurbish damaged footings identified by regular inspections to assure the safety and performance of the tower.
- Address the issues associated with the 69 tower foundations reported to be in Very Poor condition, C5.

¹³ AS/NZS 7000:2016 Overhead Line Design – Detailed Procedures.

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Appendix A Proposed Structure Footing Refurbishment Program

Circuit Name	220KV	275KV	330KV	500KV	66KV	Grand Total
DDTS-SMTS 2			6			6
YPS -ROTS 8	5					5
HOTS-RCTS	4					4
HWPS-ROTS 2	4					4
BETS-KGTS	3					3
DDTS-SHTS	3					3
HWTS-ROTS 3				3		3
SHTS-BETS	3					3
BATS-TGTS	2					2
DPS -MBTS	2					2
MLTS-BATS 1	2					2
MLTS-ELTS	2					2
MLTS-TRTS 1				2		2
TTS -BTS 1	2					2
TTS -KTS 1N	2					2
YPS -ROTS 6	2					2
CSTS-TSTS				1		1
EPS -TTS L	1					1
GNTS-SHTS 1	1					1
HWPS-ROTS 1	1					1
HWTS-CBTS 4				1		1
HWTS-SMTS 2				1		1
HYTS-SESS 2		1				1
KTS -WMTS 2	1					1
KTS-DPTS 2	1					1
MBTS-DDTS 1	1					1
MRTS-RCTS	1					1
MSS -DDTS 1			1			1
MWTS-LY 1					1	1
ROTS-MTS 3	1					1
SMTS-KTS				1		1
SMTS-TTS 2	1					1
SYTS-MLTS 1				1		1
SYTS-MLTS 2				1		1
YPS -ROTS 5	1					1
WETS-RCTS	1					1
Grand Total	47	1	7	11	1	67